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16. Abstract

The subject of automated verification of vehicle occupancy is explored in FHWA's HOV Pooled-Fund Study white paper, *Automated Vehicle Occupancy Verification Technologies*, which highlights the challenges of passenger counting for high-occupancy vehicle lane enforcement and reviews potential technologies. The primary purpose of this companion document is to define the critical needs of facility operators, or end users, for automated vehicle occupancy verification (AVOV) applications and how these needs can best be implemented within existing and planned ITS infrastructure. In the case of AVOV systems, this entails identifying the various ways in which occupancy information will be acquired, what other information is needed to make the occupancy information meaningful, how it is communicated to other systems, and how the occupancy information will be used. The concept of operations represents the first step in the systems engineering process and documents key aspects about the proposed system, including the reference physical architecture, architectural needs, and system features to support defined user needs.

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Advanced Vehicle Occupancy Verification Concept of Operation:

Supplement to the Research White Paper on Automated Vehicle Occupancy Verification (AVOV) Technologies

Prepared for the HOV Pooled-Fund Study
of the
U.S. Department of Transportation
Federal Highway Administration

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1. Introduction

This document examines the problem of integrating a roadside Advanced Vehicle Occupancy Verification (AVOV) system into current and future intelligent transportation systems (ITS) networks. The primary purpose of this document is to define the critical needs of facility operators, or end users, for an AVOV application and how these needs can best be implemented within existing and planned ITS infrastructure. Accepted system engineering processes detail that requirements should only be developed to fulfill well-defined user needs. The first stage in this process is to identify the ways in which a system will be used. In the case of AVOV systems, this entails identifying the various ways in which occupancy information will be acquired, what other information is needed to make the occupancy information meaningful, how it is communicated to other systems, and how the occupancy information will be used.

This concept of operations provides the reader with:

a. A detailed description of the scope of this document;
b. An explanation of how an AVOV is expected to fit into the larger context of an ITS network; and
c. A starting point in the systems engineering process.

The intended audience of this concept of operation includes representatives of state departments of transportation (DOTs), metropolitan planning organizations (MPOs), transit agencies, enforcement agencies, and others having a role in the planning, management, operation, and enforcement of high-occupancy vehicle (HOV)/high-occupancy toll (HOT) lane facilities. Targeted end users of the white paper are first level supervisors, technical staff (planners and operators), and public safety and enforcement agencies involved in the planning, development, and implementation of HOV/HOT enforcement policies and programs, as well as developers of automated occupancy verification systems and the research community.

Managers, operations personnel, and engineers will find this section useful in order to understand how AVOV equipment can be used in their system. For this audience, this concept of operation serves as the starting point in the procurement process. They will be able to familiarize themselves with each feature covered by the document and determine whether that feature is appropriate for their implementation. If it is, then their procurement specification will need to require support for the feature and all of the mandatory requirements related to that feature.

Systems integrators, developers, and researchers will find this concept of operations useful in order to gain a more thorough understanding as to why the more detailed requirements (as specified in a subsequent document) exist.

2. Tutorial

A concept of operations describes a proposed system from the users' perspective. Typically, a concept of operations is used on a project to ensure that the system developers understand the users' needs and that they develop the right product.

Within the context of ITS standards, the concept of operation is the initial step in a system engineering process that enhances the quality, correctness, and effectiveness of a system under consideration. Figure 1 illustrates the steps in the system engineering process. The steps are shown in the shape of a "V" to emphasize that each step in the development side (left hand) has a corresponding verification or validation step on the right side to check correctness. It also serves as the starting point for users to select which features may be appropriate for their project.

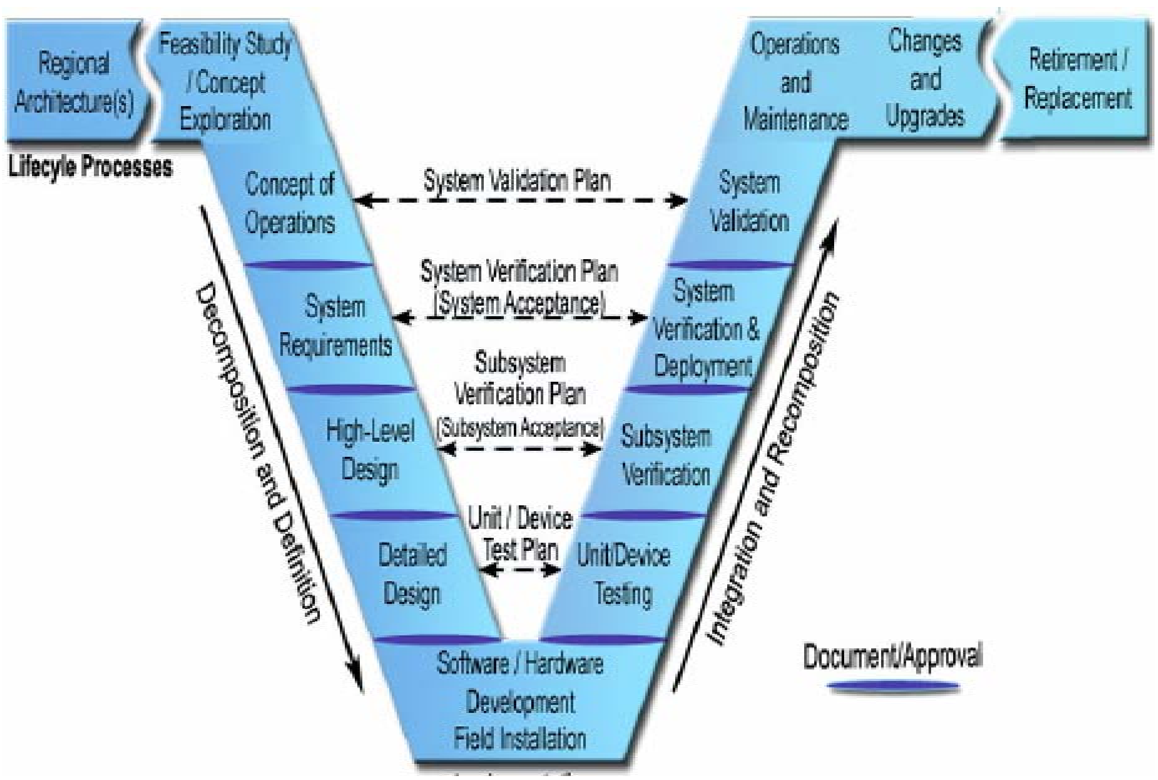

Figure 1. Systems Engineering V Diagram

The concept of operations starts with a discussion of the current situation and problems that have led to the need to AVOV systems covered by the scope of the document. This discussion is presented in layman's terms such that both the potential users of the system and the system developers can understand and appreciate the situation.

The concept of operations then documents key aspects about the proposed system, including the:

a. Reference physical architecture – The reference physical architecture defines the overall context of the proposed system and defines which specific interface is addressed by this concept of operation. The reference physical architecture may be supplemented with one or more samples that describe how the reference physical architecture may be realized in an actual deployment.

b. Architectural Needs – The architectural needs clause discusses the issues and needs relative to the system architecture that have a direct impact on this concept of operation.
c. Features – The features identify and describe the various functions that users may want the device to perform. These features are derived from the high level user needs identified in the problem statement but are refined and organized into a more manageable structure that form the basis of the traceability tables that come later.

The architectural needs and features are collectively called the *user needs*. A systems requirements document uses these user needs in the analysis of the system in order to define the various functional requirements of a vehicle occupancy device. Each user need must be traced to one or more functional requirements and each functional requirement must be derived from at least one user need. A traceability matrix, such as shown in Table 1, is then typically used to show the correlation or mapping between user needs and functional requirements.

Note: Off-the-shelf interoperability and interchangeability can only be obtained by using well-documented user needs, along with their corresponding requirements and design that are broadly supported by the industry as a whole. Designing a system that uses environments or features not defined in a standard or not typically deployed in combination with one another will inhibit the goals of interoperability and interchangeability, especially if the documentation of these user needs is not available for distribution to system integrators. Vehicle occupancy standards allow implementations to support additional user needs in order to support innovation, which is constantly needed within the industry; but users should be aware of the risks involved with using such environments or features.

Table 1. Traceability Table Example

User Need ID	User Need	FR ID	Functional Requirement	Conformance	Project Requirement	Additional Project Requirements
2.4	Architectural Needs			M	Yes	
2.4.1	Generic Architectural Needs			M	Yes	
2.5	Features			M	Yes	
2.5.1	VO Manager Features			M	Yes	
2.5.1.1	Generic Features			M	Yes	
2.5.1.2	Monitor Controller Status			O	Yes / No	
		3.5.1.2.1	Retrieve Controller Status	M	Yes / NA	
2.5.1.3	Monitor Mobile Station Data			Mobile:M	Yes / NA	
		3.5.1.3.1	Retrieve Mobile VO Movement	M	Yes / NA	
2.5.2	Sensor Manager Features			O.1 (1..*)	Yes / No	
2.5.2.1(Occupancy)	Monitor Vehicle Occupancy			O.3 (1..*)	Yes / No / NA	
		3.5.2.3.2.1	Retrieve Vehicle Occupancy	M	Yes / NA	
		3.6.2.1	Required Number of Occupancy Sensors	M	Yes/NA	The AVOV shall support at least 3 occupancy sensors per lane.
2.5.2.1.2	Monitor			O.3 (1..*)	Yes / No / NA	
		3.5.2.3.2.2		M	Yes / NA	

3. AVOV and ITS Architecture

The Automated Vehicle Occupancy Verification Technologies white paper presents an introduction to tradition HOV/HOT enforcement practices, provides a description of several AVOV systems, and presents an overview of current research and development. Because roadside and in-vehicle systems are different in their approaches to occupancy verification, each one is looked at in terms of sensing technologies, challenges and functional requirements, and the technology trends and future outlook. The telemetrics for in-vehicle systems are also discussed. The white paper also covers legal and privacy considerations, gives a statutory framework, discusses resolving concerns, and presents material on the role of public education in regard to occupancy verification.

The above topics, as presented in the Automated Vehicle Occupancy Verification Technologies white paper, form the basis of the Feasibility Study/Concept Exploration step of the system engineering process, shown in Figure 1. These topics serve as the discussion of the current situation and problem statement for this concept of operations. The following sections identify the architectural features of ITS infrastructure that are salient for the integration an implementation of AVOV systems of varying complexity.

Annex A introduces a number of features/requirements that may be desirable when a AVOV is part of an ITS and must be interoperable in a National Transportation Communications for ITS Protocol (NTCIP) center-to-field environment.

3.1. Reference Physical Architecture

This concept of operation addresses the communications interface between a management station and an external vehicle occupancy detector controller (it does not address onboard systems). The following paragraphs further explain the typical physical architectures that may be used in conjunction with vehicle occupancy detectors and are addressed by this document.

3.1.1. Typical Physical Architecture

This concept of operation addresses the communications interface between a management station and a vehicle occupancy verification system. The relationship between the two entities is depicted in Figure 2. One should realize that the actual physical arrangement of these components might vary from deployment to deployment and operational needs. In particular, the vehicle ID portion of the system may not be needed in some architectures. In some cases, the vehicle ID may not be an electronic ID but rather a picture.

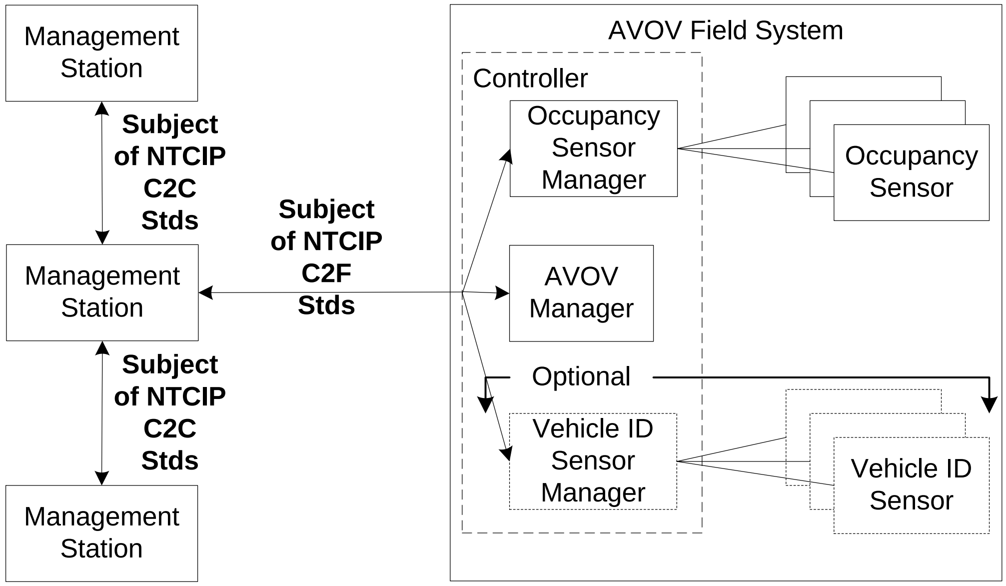

Figure 2. Reference Architecture

The major components of the system are as follows:

a. **Management Station –** One or more host computing platforms that manage one or more field devices, such as an AVOV. Management stations are typically located in some type of management center (e.g., a Traffic Management Center) and may be a considerable distance from the AVOV. Other types of management stations include maintenance laptops that a field technician may use on a trip to visit the device or a computer workstation that monitors fault conditions. The responsibilities of a management station may include configuring, monitoring, and processing vehicle occupancy information. The vehicle occupancy information may be processed by the management station to apply toll charges or be passed along to other management stations or subsystems that access toll charges.
b. **AVOV –** An Advanced Vehicle Occupancy Verification Controller and its connected equipment, such as occupancy detector and vehicle identification sensors.
c. **Controller –** A host-computing platform that is used to manage the collection and reporting of sensor data and/or to manage the acquisition of vehicle occupancy information. It includes an AVOV Manager, an Occupancy Sensor Manager, and possibly, a Vehicle ID Sensor Manager. The controller is responsible for continually monitoring operating conditions. When a controller receives a request from a management station, it shall immediately respond with its most recent reading for that data. A system operator should be aware that the nature of some information may require significant time to collect (e.g., HOV vehicles and occupancy counts), or may be dated (e.g., information stored in a log); thus the information contained in the response may have been collected some time prior to the request being sent.
d. **Occupancy Sensor Manager –** The portion of the controller that manages the collection and reporting of occupancy sensor data.
e. **Vehicle ID Sensor Manager –** The portion of the controller that manages the collection and reporting of vehicle identification sensor data.
f. **AVOV Manager –** The portion of the controller that deals with general functionality

that applies to both sensor management and field device management.

The following subclauses describe sample physical architectures that are supported by this reference architecture.

3.1.2. Manual AVOV Device

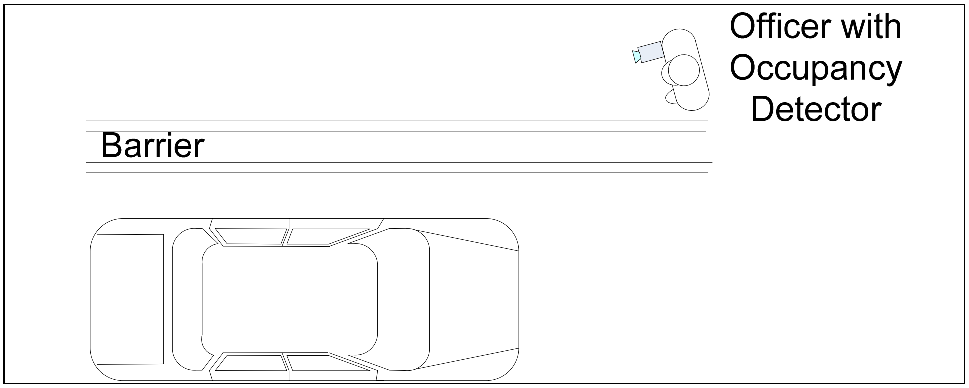

Figure 3. Portable Vehicle Occupancy Verification

Figure 3 illustrates a handheld implementation of a vehicle occupancy verification device. A patrolman uses the ability of an advanced technology sensor to rapidly and accurately scan vehicles to determine a vehicle passenger count. In this architecture, the patrolman may also connect the occupancy detector to a laptop or computer workstation as illustrated in Figure 4. The laptop or workstation could be used for configuring the device and/or act as a long-term storage device for the information gathered in the field. This concept of operation covers the communications interface between the detector and laptop/workstation.

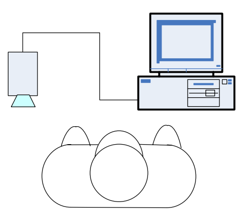

Figure 4. Handheld Vehicle Occupancy Monitor and Computer

3.1.3. Integrated Vehicle Occupancy Verification

Figure 5 and Figure 6, respectively, illustrate the physical and systems architecture where a vehicle occupancy sensor system is integrated into toll collection system. In this architecture, configuration, control, and monitoring of the occupancy detector may be internal to the toll collection system. Alternately, configuration, control, and monitoring may be external and be provided by a management station that communicates with AVOV component of the toll collection system.

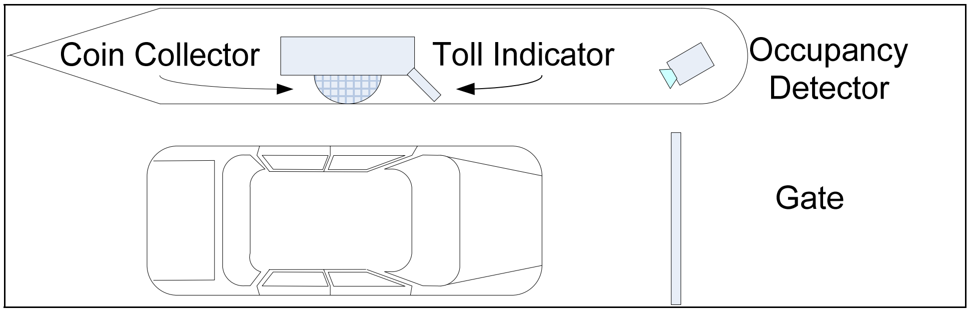

Figure 5. Automated Vehicle Occupancy Toll Collector System

In this document, the discussion of the interface for configuration, control, and monitoring of an AVOV component is restricted to the case where the AVOV component is external to the toll collection system. Neither an internal interface between the occupancy detector AVOV component nor an internal interface between the AVOV component and the toll collection system are addressed by this document.

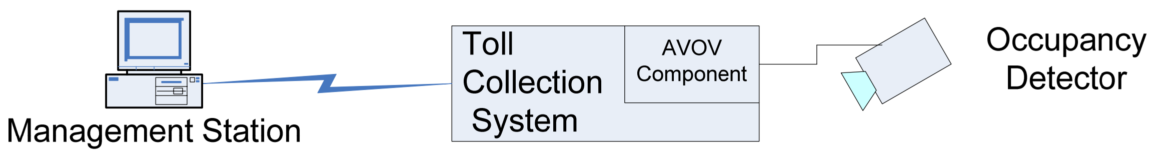

Figure 6. Integrated Vehicle Occupancy Verification

3.1.4. Remote AVOV Station

Figure 8 depicts an architecture where the occupancy sensor is coupled with a vehicle ID sensor so that it can operate autonomously in a remote location. This could correspond to a system mounted on an overhead gantry system shown in Figure 7, for example. The controller could be mounted on one of the gantry uprights or be ground mounted some distance away. The figure illustrates the controller connecting to its Management Station via a wireless radio link, but any type of wireline communications would do.

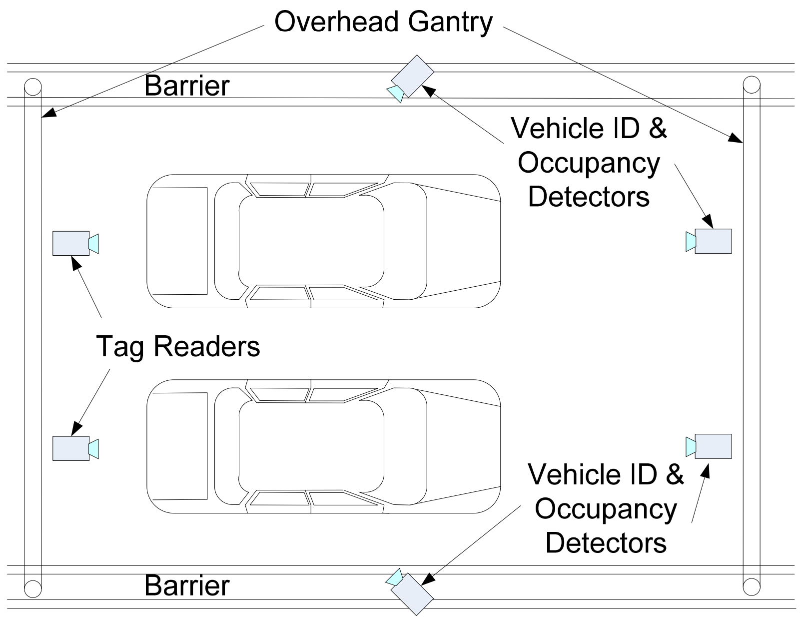

Figure 7. Fully Automated Vehicle Occupancy Detection System

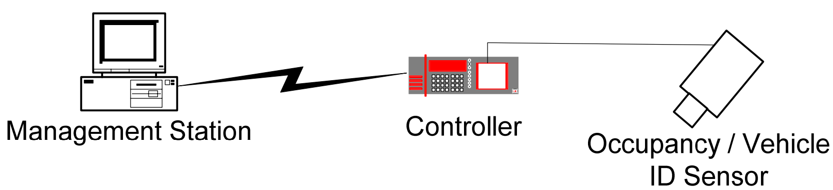

Figure 8. Remote Vehicle Occupancy Monitoring Station

3.2. Architectural Needs

The following subclauses define the communications environment within which an AVOV is expected to operate.

3.2.1. Generic Architectural Needs

This concept of operation addresses the interface between an AVOV system and one or more management stations (e.g., central computers, laptops, etc.). The data collected by the AVOV may include data from multiple sensors. When communicating with a management station, each reading must be clearly associated with a specific sensor. Once the management station has retrieved the data of interest, toll processing takes place and an operator may use this information to make decisions about managing the transportation system.

In order to enable communications between these components, the transportation system manager will need to establish a communication system that links the AVOV with a management station. For some systems, the cost of communications may be minimal and as such the system may be designed for constant polling; other systems may encounter significant costs for communicating with the AVOV and as such the system may be designed to minimize data exchanges. When deploying an AVOV, the system designer must consider which of the following operational environments in the subsequent subclauses, need to be supported.

Note: This concept of operation is written as a section of an NTCIP center-to-field information standard. Normally a concept of operation focuses on user needs and not on solutions. However, is there a need for AVOV to operate as field device in the National ITS Architecture? If so, and the NTCIP approach to interoperability and interchangeability were followed, the task of integrating AVOV information into systems would be more economically feasible and easier to accomplish. In NTCIP, a “device” data dictionary defines the data elements and messages used to access information in a device. NTCIP also defines communication protocols or “sets of rules” used to exchange that information. If industry, as a whole, decided to develop a new AVOV data dictionary and adopt the center-to-field protocols then both system software providers and manufacturers have a standardized method of integrating AVOV into systems.

3.2.1.1 Provide Live Data

The typical operational environment allows the management system to monitor and control the device by issuing requests (e.g., requests to access information, alter information, or control the device). In this environment, the device responds to requests from the management station immediately (e.g., through the provision of live data, success/failure notice of information alteration, or success/failure of the command).

3.2.1.2 Provide Off-line Log Data

Some operational environments do not have always-on connections (e.g., dial-up links do not). In such environments, a transportation system operator may wish to define conditions under which data will be placed into a log, which can then be uploaded at a later time. For example, the operator may wish to maintain a log of when an AVOV controller keyboard was accessed.

3.3. Features

The following subclauses identify and describe the various features that may be offered by the AVOV. It is divided into the following major subclauses:

a. AVOV Manager Features
b. Occupancy Sensor Manager Features

3.3.1 AVOV Manager Features

The following subclauses identify and describe the various features that may be offered by the AVOV Manager, which is the part of the controller that performs the functionality that may apply to a Sensor Manager. It consists of the following features:

a. Retrieve Device Identity
b. Generic Features

3.3.1.1 Retrieve the Device Identity

A transportation system operator may need to determine basic information about the device, such as its location and the make, model, and version of the device components.

3.3.1.2 Generic Features

When an AVOV is integrated into an ITS and is considered an NTCIP Center-to-Field device, there are a number of features that users expect. Annex A puts these features in the context of Generic Functional Requirements.

3.3.2. Occupancy Sensor Manager Features

The following subclauses identify and describe the various features that may be offered by the Sensor Manager. It consists of the following feature:

a. Monitor vehicle occupancy

3.4. Backwards Compatibility Needs

As an initial version of this document, it does not address any backwards compatibility issues.

3.5. Security

The security issues related directly to HOV/HOT pertain to protecting the communications with an AVOV and any management station. Security should be implemented either physically by protecting the communications access points, or logically by enabling security features associated with the underlying communications protocols.

3.6. Relationship of User Needs to National ITS Architecture Flows

The National ITS Architecture depicts one Architecture Flow associated with the operation of an HOV/HOT/AVOV. The following flow is between the Roadway Subsystem and Traffic Management.

- HOV Lane Management

The architecture illustrates the subsystems and information exchanges of HOV Lane Management as shown in Figure 9.

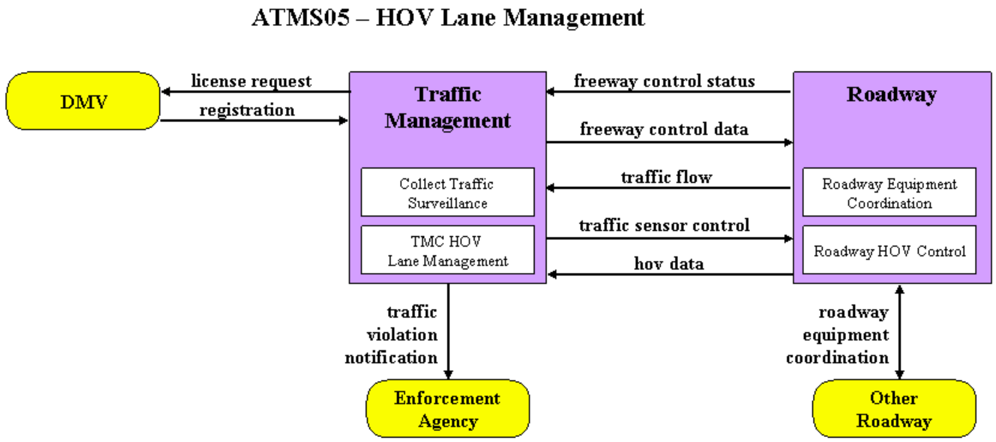

Figure 9. HOV Lane Management Subsystems and Information Flows

There are number of National ITS Architecture data flows, subflows, and primitive data elements that relate to the operation of an HOV/HOT/AVOV. These include:

- private_vehicle_occupants
- hov_sensor_data
- hov_lane_data_input
- hov_sensor_status
- hov_sensor_data
- hov_priority
- hov_lane_data
- hov_priority
- predicted_hov_lane_data
- hov_lane_list
- hov_lane_vehicle_count
- hov_lane_violation count
- hov_lane_violation
- hov_lane_identity
- hov_sensor_equip_status_for_m_and_c
- sensor_allocation_for_hov_lanes

The National ITS Architecture also enumerates the following functional requirements related HOV/HOT operation:

1. The field element shall include sensors to detect high-occupancy vehicle (HOV) lane usage, under center control.
2. The field element shall include driver information systems to notify users of lane status for lanes that become HOV or High Occupancy Toll (HOT) lanes during certain times of the day on freeways, under center control.
3. The field element shall include freeway control devices, such as ramp signals and mainline metering and other systems associated with freeway operations that control use of HOV lanes, under center control.

4. The field element shall provide traffic flow measures and information regarding vehicle occupancy (i.e., lane usage) in HOV lanes to the center.
5. The field element shall return operational status for the HOV lane sensors to the controlling center.
6. The field element shall return fault data for the HOV lane sensors to the center for repair.

Requirements from TMC HOV Lane Management:

1. The center shall remotely control sensors to detect high-occupancy vehicle (HOV) lane usage.
2. The center shall remotely control driver information systems to notify users of lane status for lanes that become HOV or High Occupancy Toll (HOT) lanes during certain times of the day on freeways.
3. The center shall remotely control freeway control devices, such as ramp signals and mainline metering and other systems associated with freeway operations that control use of HOV lanes.
4. The center shall collect traffic flow measures and information regarding vehicle occupancy (i.e., lane usage) in HOV lanes.
5. The center shall monitor the use of HOV lanes and detect vehicles that do not have the required number of occupants.
6. The center shall collect operational status for the freeway control devices associated with HOV lane control.
7. The center shall collect fault data for the freeway control devices associated with HOV lane control for repair.
8. The center shall store violation parameters, detect HOV lane violators, obtain the vehicle registration data from the appropriate State Department of Motor Vehicles (DMV) office, and then provide the capability to send violation information to a law enforcement agency.

Appendix A: External Requirements

This appendix provides a list of requirements that would be associated with an AVOV should it be considered a stand-alone device and needs to be conformant with the NTCIP suite of standards.

A.1. Generic Architectural Requirements

The field element shall provide traffic flow measurements and information regarding vehicle occupancy (i.e., lane usage) as part of the requirements from Roadway HOV Control

1. The field element shall include sensors to detect high-occupancy vehicle (HOV) lane usage, under center control.
2. The field element shall include driver information systems to notify users of lane status for lanes that become HOV or High Occupancy Toll (HOT) lanes during certain times of the day on freeways, under center control.
3. The field element shall include freeway control devices, such as ramp signals and mainline metering and other systems associated with freeway operations that control use of HOV lanes, under center control.

The field element shall also provide status information about sensors to the management center.

1. The field element shall return operational status for the HOV lane sensors to the controlling center.
2. The field element shall return fault data for the HOV lane sensors to the center for repair.

A.1.1. Support Basic Communications

Requirements for making requests are provided in the following subclauses.

A.1.1.1. Retrieve Data

A management station shall be able to retrieve any set of data from the device at any time.

A.1.1.2. Deliver Data

A management station shall be able to deliver data (e.g., configuration data, commands, etc.) to the device at any time.

Note: Other requirements may place restrictions on how the device may respond under certain scenarios.

A.1.1.3. Explore Data

A management station shall be able to dynamically discover what data and data instances are supported by the device.

A.1.2. Support Logged Data

Requirements for managing the logged data are provided in the following subclauses.

A.1.2.1. Retrieve Current Configuration of Logging Service
Upon request from a management station, the device shall return the current configuration of the event logging service, including the classes and types of events that are currently configured.

A.1.2.2. Configure Logging Service
Upon request from a management station, the device shall configure the event logging service as requested, including configuration of the event classes and event types to log.

A.1.2.3. Retrieve Logged Data
Upon request from a management station, the device shall return the event log.

A.1.2.4. Clear Log
Upon request from a management station, the device shall clear the indicated log entries of a given event class.

A.1.2.5. Retrieve Capabilities of Event Logging Service
Upon request from a management station, the device shall return the capabilities of the event logging service, including the number of classes, number of event types, and number of events that can be supported by the device.

A.1.2.6. Retrieve Total Number of Logged Events
Upon request from a management station, the device shall return the total number of events that the device has detected.

A.2. Generic Functional Requirements
Requirements for data exchange capabilities are provided in the following subclauses.

A.2.1. Generic Configuration Requirements
Requirements for configuring a device controller are provided in the following subclauses.

A.2.1.1. Retrieve Device Component Information
Upon request from a management station, the device shall return identification information for each module contained in the device including:

a. An indication of the type of device,
b. The manufacturer of the module,
c. The model number or firmware reference of the module,
d. The version of the module, and
e. An indication of whether it is a software or hardware module.

A.2.1.1.1. Retrieve Device Configuration Identifier
Upon request from a management station, the device shall return a code that will only change when changes are made to the controller configuration.

A.2.1.1.2. Retrieve Supported Standards
Upon request from a management station, the device shall return the NTCIP information and communications standards, which it supports.

A.2.1.1.3. Retrieve System Name
Upon request from a management station, the device shall return the system name of the device.

A.2.1.2. Manage Time
Requirements for managing the controller’s clock are provided in the following subclauses.

A.2.1.2.1. Set Time
Upon request from a management station, the device shall set the coordinated universal time to that requested.

A.2.1.2.2. Retrieve Current Time
Upon request from a management station, the device shall return the current time settings within the controller.

A.2.1.3. Generic Status Monitoring Requirements
Requirements for monitoring the status of a device controller are provided in the following subclauses.

A.2.2. Generic Supplemental Requirements
Supplemental requirements are provided in the following subclauses.

A.2.2.1. Supplemental Requirements for Event Monitoring
Supplemental requirements for monitoring for the occurrence of certain events are provided in the following subclauses.

A.2.2.1.1. Record and Timestamp Events
Upon detection of a configured event, the device shall record the event type, the current time, and the configured log information in a local log (log contained in the device controller).

A.2.2.1.2. Support a Number of Event Classes
The device shall support the number of event classes as defined by the specification. If the specification does not define the number of event classes, the device shall support at least one event class.

A.2.2.1.3. Support a Number of Event Types to Monitor
The device shall support the number of event types as defined by the specification. If the specification does not define the number of event types, the device shall support at least one event type.

A.2.2.1.4. Support Monitoring of Event Types
Supplemental requirements for monitoring types of events are provided in the following subclauses.

A.2.2.1.4.1. Support On-Change Events
The device shall allow any event type configuration to monitor data for changes in value.

A.2.2.1.4.2. Support Greater Than Events
The device shall allow any event type configuration to monitor data for values exceeding a defined threshold for a period of time.

A.2.2.1.4.3. Support Less Than Events
The device shall allow any event type configuration to monitor data for values falling below a defined threshold for a period of time.

A.2.2.1.4.4. Support Hysteresis Events
The device shall allow any event type configuration to monitor data for values exceeding an upper limit or dropping below a lower limit.

A.2.2.1.4.5. Support Periodic Events
The device shall allow any event type configuration to monitor data on a periodic basis.

A.2.2.1.4.6. Support Bit-flag Events
The device shall allow any event type configuration to monitor one or more bits of a value becoming true (i.e., obtaining a value of one).

A.2.2.1.5. Support Event Monitoring on Any Data
The device shall allow any event type configuration to monitor any piece of data in the device within the logical rules of the type of event (e.g., ASCII strings should not be monitored with greater than or less than conditions).

A.2.2.1.6. Support a Number of Events to Store in Log
The device event log shall support the number of events as defined by the specification. If the specification does not define the number of events for the log, the device shall support at least one event in the log.